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SYSTEMATIC APPROACH TO OPTIMIZE COST DRIVERS BASED ON LIFE CYCLE COST MODELING

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Abstract

Optimizing cost drivers is one of the key success factors within product development. Approaches to develop cost-efficient products are deeply rooted in standard design methodology. However, in most instances manufacturing costs are in primary focus. Against the background of current trends in various industries, the life cycle of a product becomes more and more important, which results in the necessity of considering costs from the use phases as well. Designing a product with low life cycle costs poses a significant challenge. Various dependent influences lead to trade-off decisions with the involvement of subject matter experts. Focus on the most important cost influences in different life cycle phases is essential for a fast, efficient, and standardized process to optimize costs. This paper describes a holistic life cycle costing approach for cost management in product development. Based on cost modeling, a systematic way to optimize capital and operational cost drivers is explained. Relations and trade-offs between costs from different phases of the life cycle are presented. Also, a case study performed with an industry partner demonstrates the application of the model.

Keywords: Design costing, Design methodology, Product Lifecycle Management (PLM), Cost drivers

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1 INTRODUCTION

The goal of every market-driven company is to increase profit. Due to the fact that profit is the resulting difference of revenue and cost, there are two ways to achieve this goal. One option is to raise the revenue, which can be realized by various actions like improved sales, shorter delivery times, as well as better product/service quality. The second approach is to reduce the total cost, which can be accomplished by rationalizing the product manufacturing process or developing cost-efficient products (Ehrlenspiel et al., 2007). To gain the highest possible outcome, these optimizations are usually performed in parallel. This paper focuses on reducing system cost with a methodical approach.

Over the entire life cycle, operational costs are often many times greater than one-time capital expenditures (Farr, 2011). Consequently, technical literature and companies increasingly consider life cycle costs and not only manufacturing costs (Blanchard, 2008). Life cycle costs are defined as "discounted cumulative total costs incurred by a specified function or item of equipment over its life cycle" (ISO 15663-1, 2000). As a synonym, the term "total cost of ownership" is also often used (Kara, 2014). Up to 75% of life cycle costs are determined after the product´s design stage. Afterward this point, it is challenging, and in some instances not possible, to influence costs anymore (Ehrlenspiel et al., 2007). Costs for changes increase exponentially in every stage during the product life cycle, which is described by the "rule of ten" (Neff et al., 2000). Cost management within the product development offers large saving potentials. Life cycle cost modeling can contribute to cost reduction by identifying cost drivers and how changes in design parameters affect cost (Asiedu and Gu, 1998).

2 STATE OF THE ART

Approaches to reduce costs are deeply rooted in design methodology. These approaches have been described in technical standard literature like Pahl/Beitz (1996) for decades. Koller (1994), for example, defined simple rules to optimize the manufacturing cost of parts. Material cost can be decreased by using less or cheaper material. As an analog, less and cheaper operations in production and assembly can lower costs.

However, recent technical literature emphasizes the multitude of influences on product cost. Ehrlenspiel et al. (2007) described them in detail as well as alternate rules for a cost-efficient design. Many of these influences exceed the actual design task. Elements like concept, shape, size, dimension, material, and manufacturing process can be influenced by changes to the product. However, product quantity, requirements, degree of outsourcing and many variants are management-driven decisions. Each of these influences can be optimized by several actions that affect various departments in the company. An illustration of the influence of variant management is shown in Figure 1.

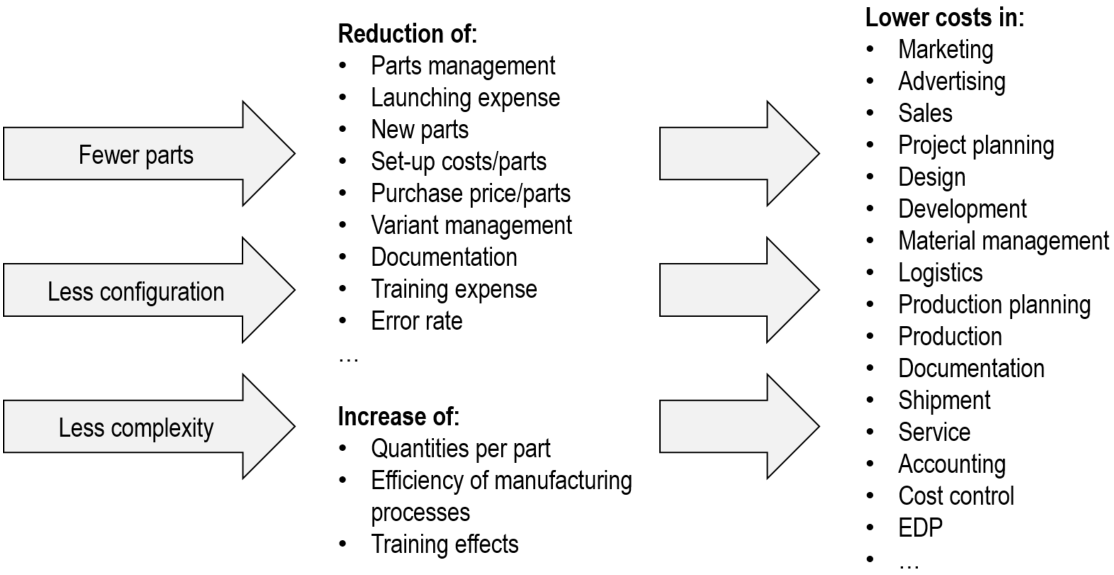


Figure 1. Reducing product cost with less variants (Ehrlenspiel et al., 2007)

Variant management has the goal of reducing the quantity of different parts and simplifying configuration and complexity. This approach results in many different kinds of improvements, e.g. the reduction of parts management or documentation as well as the increase of quantities per part. These optimizations can lead to lower cost in almost every department in the company, including marketing, sales, development, logistics and accounting.

A very large number of possibilities influence product cost, and performance optimizations are often difficult to measure. In this paper the life cycle costs of a product shall be optimized. As a result, cost from other phases than manufacturing, especially the use phase, must be considered. Challenges exist in trade-offs, e.g., in optimizing production and operation costs (Marten and Gatzen, 2014). Optimizing both at the same time is often not possible (Woodward, 1997). This reality is illustrated by the following example. If a cheaper raw material for a part is used, production costs can decrease. If this material meets the requirements regarding yield stress, tensile strength and hardness, it can be chosen from the mechanical and design point of view. The designer, though, must consider that this material may have, due to its lower quality, less corrosion resistance, resulting in an increased wear and higher operational cost. The technical solution with lowest production cost is, therefore, often different from the one with the lowest life cycle cost (see Figure 2).

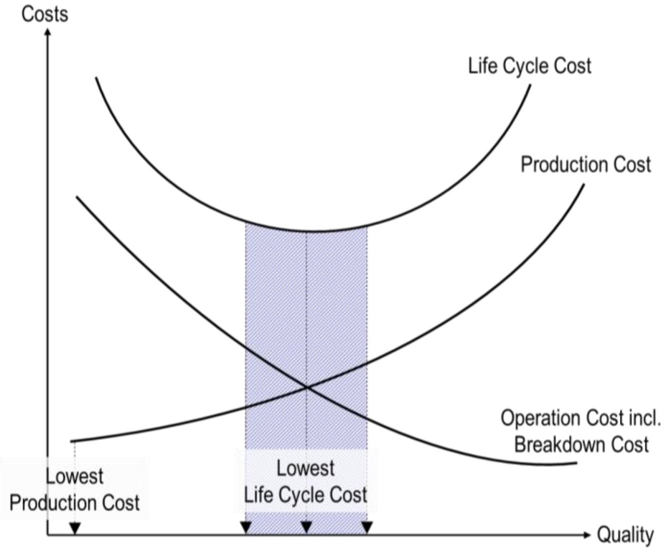


Figure 2. Trade-off production and operation cost (Woodward, 1997)

Against this background, one common approach within methodical product development is the "Design for X" (DfX) concept (Hepperle, 2013). This concept was developed to increase customer satisfaction with high quality and low life cycle costs (Bralla, 1995). The "X" is a placeholder for a specific objective, a life cycle phase (e.g., manufacturing, assembly) or an essential feature (quality). DfX is a method to determine later in the life cycle occurring costs already in development and to initiate design changes to minimize costs. The challenge is to identify direct and indirect interdependencies between different DfX guidelines (Bauer and Paetzold, 2006).

When a development project is started, within the analysis of possible business cases, the costs are determined and set as a requirement. The business case evaluates a scenario of an investment from the economic point of view (Lester, 2014). The ultimate goal of DfX is to develop products and services that meet or exceed the business case by integrating subject matter experts (SMEs) from all relevant enterprise disciplines and holistically focussing on reducing life cycle costs (see Figure 3) (Gatzen et al., 2013).

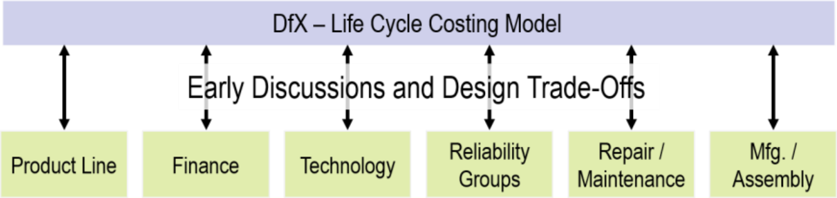


Figure 3. Trade-off discussions within DfX (Marten and Gatzen, 2014)

Most life cycle costs are determined with the design concept, so DfX models must be implemented in the concept phase. The development of a product is typically an iterative process. Consequently, expert knowledge from different departments is necessary. An important role is taken by the SMEs who support the design team. They can evaluate possible effects on the life cycle caused by changes to the concept. In particular, the high rate of exchange between DfX design criteria and the repetitive reviews provide a fulfillment of the requirements. In parallel, concepts are evaluated by the engineering team and SMEs regarding feasibility and risks (Gatzen et al., 2013). Feasibility is often analyzed with the assessment of the technical readiness level (TRL). Risks are rated with failure mode and effects analysis (FMEA). The process is depicted in Figure 4.

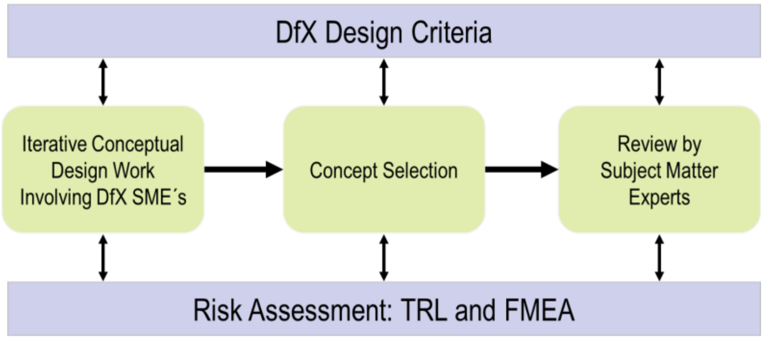


Figure 4. Process of developing and selecting a concept

The process for a cost-efficient life cycle development is very complex, due to the enormous number of influences. The involvement of SMEs is necessary. However, who is interviewed at which time is unspecified. Therefore, an expert's information can become lost or arrive too late to be considered in the design process.

This situation requires an approach that provides a standardized procedure to optimize life cycle costs. The most important aspects regarding costs in different life cycle phases require focus so the solution space becomes delimited. Afterwards, selected SMEs can be interviewed for specific information. The selection and evaluation of cost aspects must be supported with a computer-aided model.

3 LIFE CYCLE COSTING APPROACH

The cost driver optimization is part of a holistic life cycle costing approach, which is described in this section. Product life cycles can be divided into four phases: development, manufacturing, use and recycling. Life cycle costing should be performed to achieve the maximum benefit for a product or project (IEC 60300, 2004). Developers and engineers are interested in that part of life cycle costs they can influence with their design. As a result, it is often not efficient to determine all costs that occur in the life cycle. Development costs alone are not related to the actual design, they are influenced by the way the product is developed (number of resources and their use) (Asiedu and Gu, 1998). In addition, development cost can be tracked easily with commercially available enterprise resource planning (ERP) systems. Therefore, development costs are not modelled within this approach. Costs from the manufacturing and use phase are highly influenced by the design and greatly impact the overall life cycle cost (Ehrlenspiel et al., 2007). Production costs follow and are considered as capital expenditures (CapEx) and costs from the use phase as operational expenditures (OpEx). Life cycle costing is usually performed for capital equipment, which has a very long life cycle. For this long period of time it is extremely difficult to estimate commodity prices. In addition, a cost-efficient design regarding CapEx and OpEx pursues the same goal as an optimized recycling (less material and energy in manufacturing, easier assembly and disassembly in the use phase). Due to these facts, recycling cost is not considered.

Successful cost management of product systems must answer the following three questions (Steven et al. 2008, Soth 2011):

1. How much may the product cost?
2. How much will the product cost and what are the cost drivers?
3. How can cost be optimized?

Based on these questions, the three necessary activities—cost benchmark, cost prediction and cost optimization—can be derived. Within cost benchmarks the actual capital and operational cost of the internal predecessor or a competitive product are determined. All activities regarding cost prediction estimate, compare, and analyze the life cycle cost of different concepts and later the final product. Within cost optimization, saving potentials are identified and design changes implemented.

A method requires a standardized procedure. Therefore, all three activities are performed by a defined person with a specified process, supported by models that are implemented as software tools. This is depicted in Figure 5.

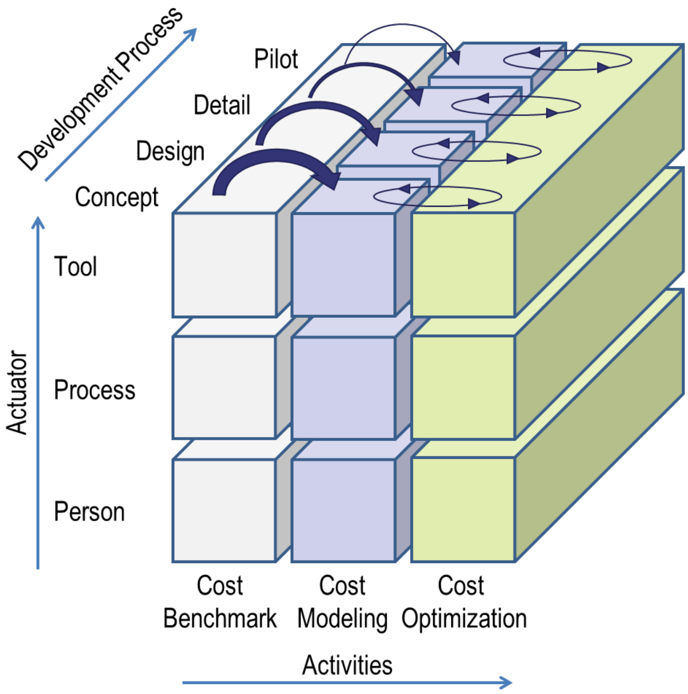


Figure 5. Holistic life cycle costing approach

The cost optimization, which is the focus of this paper, is based on the information from cost prediction. During development, the level of detail of the product and available information increase. Consequently, the calculation bases change constantly. There are different cost estimation methods that have advantages and disadvantages in their application (Kerzner, 2006). Parametric cost estimating is based on cost estimating relationships and is analogous to cost estimation used in early design phases. Direct engineering and manufacturing estimates have higher prediction accuracy, but need a first version of a bill of material and are therefore rather applicable in later phases (Blanchard, 2008). Against this background, one prediction model for the whole development process does not yield to optimal results. Instead, different connected models are necessary to use all benefits and provide best performance. These models are described in detail in Johannknecht et al. (2016a, 2016b). Therefore, the results of the cost prediction can be assumed as given for the following cost driver optimization.

4 COST DRIVER OPTIMIZATION

A cost driver is an element that has a major impact on the life cycle cost (IEC 60300, 2004). After identifying a cost driver, it is important to analyze causes of the high cost by establishing cause-and-effect relationships (Kawauchi and Rausand, 1999).

Based on spreadsheet-developed software, the cost drivers are analyzed with a systemic procedure for cost-saving potentials. Consequently, different cost topics are implemented and inquired within user forms, which enables a standardized, fast, and efficient analysis. The cost topics are connected to each other to identify possible trade-offs.

4.1 Capital Expenditures (CapEx)

First, the CapEx drivers are analyzed. All parts of the cost prediction model (see section 3) are imported into the optimization tool and sorted by descending order of their estimated production cost. Parts, which are cumulated 80% of the total cost, are considered. According to Pareto principle, this number of parts represents approximately 20% of the total parts in the system (Milgram, Spector and Treger, 1999), so even in complex technical systems the number of parts is manageable. Every part passes consecutively through the developed CapEx optimization procedure. In this procedure, six categories, each with three iteration levels, are analyzed. Function and properties of a technical product are determined by its design and material (Koller, 1994). The categories within CapEx optimization are based on design parameters that are described by various authors (Roth, 2000/ Ponn, 2008/ Ehrlenspiel et al., 2009). Therefore, the parameters of material, surface and tolerances are taken as categories. The design parameters, geometry and topology, are very complex and describe in a mathematical way. Changes are difficult to measure. Due to this reason the model considers instead primarily the radii of the parts. Radii are simple to describe and are an important factor within manufacturing cost. Secondary, the opportunity to use components-off-the-shelf (COTS) is implemented as a category and analyzed to determine if their designs can be replaced by purchasable parts (make-or-buy decisions) (Ehrlenspiel et al., 2007). In addition, the COTS request can be used as a criterion for exclusion of further optimization, as it is assumed that the design of purchased parts cannot be changed. Within the design of a part, process and technology parameters regarding the manufacturing must be determined (Vajna et al., 2009). Furthermore, the manufacturing type has a high impact on CapEx. Therefore, the manufacturing process itself is considered as the last category.

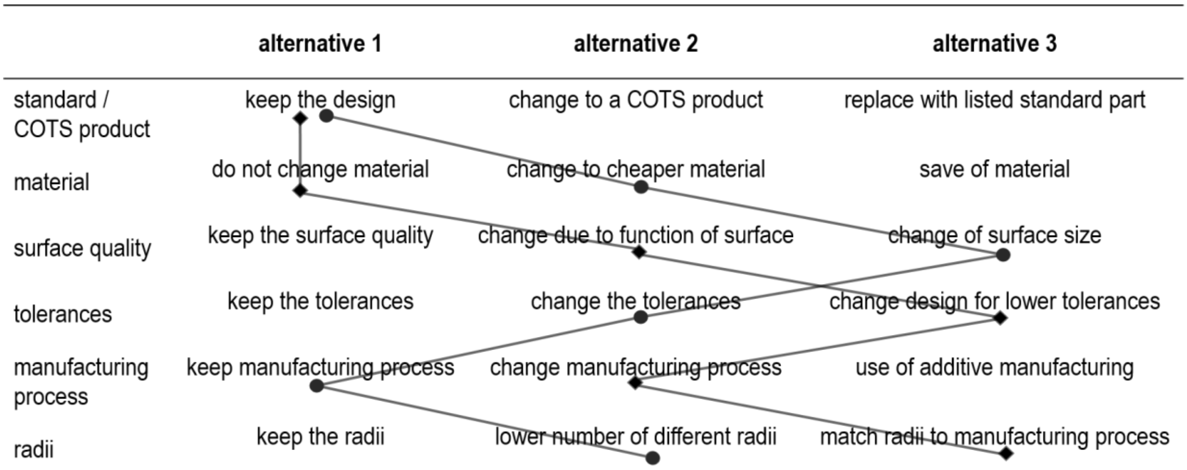
As mentioned, every part is analyzed by the user according to the categories with support of the optimization tool. Every category consists of three review levels, resulting in three possible alternative solutions. Due to this reason the review level are becoming more specific, and the next level is displayed only if the previous solution was possible. This is clarified in the following two examples.

The first category is the review on the possibility of using a COTS. The first review level determines if the part is a unique design. If not, the only alternative is to keep the design, because purchasable parts cannot be influenced by the developer. If the part is an own design, it is reviewed if this is necessary. The alternative is to change the part to a COTS. If a unique design is necessary the third level reviews if it is possible to replace the design with an already existing part from the company module catalogue. The developer is supported in the reviews by the macro-based optimization tool, an automated tool that identifies purchase parts or searches in the company internal design database for similar parts.

The second category analyzes the raw material of the parts. First it is determined if the used raw material is a standardized material in the company. Analysis then verifies if a less-expensive material with the required properties has been checked. Last, the opportunity of saving material is reviewed. The optimization tool interfaces with the material database and analyzes possible alternatives after the developer has varied the material parameters like yield and tensile strength, hardness or requirements such as nonmagnetic properties.

Reviews in the remaining four categories are then performed. In the surface category, the review focuses on the quality. For different kind of surfaces (e.g., functional surfaces) values are recommended by the optimization tool. An integrated calculator for tolerances reviews also the requirements in its category. The manufacturing process is reviewed by parameters like lot size or ratio of machining (if applicable) that enable a rough estimation if another possible manufacturing process is more cost-efficient. The results can be a basis for further discussions. In the last category, radii are analyzed on their manufacturability. Consequently, standardized milling cutters are implemented.

After a part passes all six categories, the evaluation is summarized in a morphological box (Figure 6). Possible solutions with different alternatives in the categories are demonstrated in the optimization tool.



	alternative 1	alternative 2	alternative 3
standard / COTS product	keep the design	change to a COTS product	replace with listed standard part
material	do not change material	change to cheaper material	save of material
surface quality	keep the surface quality	change due to function of surface	change of surface size
tolerances	keep the tolerances	change the tolerances	change design for lower tolerances
manufacturing process	keep manufacturing process	change manufacturing process	use of additive manufacturing
radii	keep the radii	lower number of different radii	match radii to manufacturing process

Figure 6. Example of filled morphological box - CapEx

4.2 Operational Expenditures (OpEx)

The second optimization step considers OpEx drivers. The evaluation of a design for maintainability is more difficult than for manufacturability. The traditional approach to maintainability treats the sustainment of the product´s reliability, which is often a misconception and viewed as an operational procedure rather than a challenge to be solved by design (Gardner and Sheldon, 1995). Concrete principles and rules to design a product for an efficient disassembly and assembly are rare in literature - for example by Taylor (2014). Analogy to the CapEx, the OpEx optimization considers six categories with three review levels each. The categories are based on an analysis of the most influencing elements on operational cost. The analysis was done in the company in which the case study was performed (see section 5). It is important to mention that the view on a single part within OpEx optimization is in some cases not a productive approach. For maintenance, the interaction of different parts or assemblies must be considered.

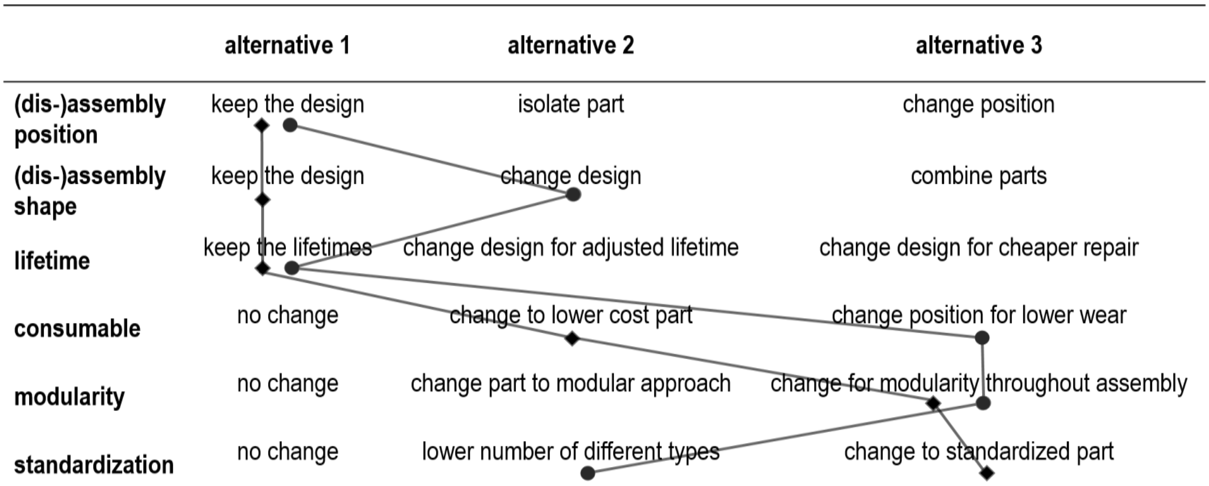
The calculated OpEx drivers and further cost analysis information from the use phase of the product are delivered by the life cycle costing model (see section 3).

First, two review categories are assembly/ disassembly of a part regarding its shape and its position. Because there are very different kinds of parts and nearly endless possible solutions, the review can be only realized in a qualitative way. Consequently, both reviews should be seen as thought-provoking impulses. The objective is to reduce cost for assembling and disassembling parts within maintenance. This shall be achieved by an easier and faster access to parts, which are frequently changed. Changing the position of a part can reduce labor time and therefore costs. The shape is referencing on the geometry of a single part. Within this category, an easier access to the cost driver by changing the design of the part is reviewed.

The third category is named maintenance strategy. In this review the whole product is considered. In the life cycle costing model a lifetime for all parts is deposited. Further, maintenance levels are defined for most products. In a car, for example, maintenances are often determined after a specific number of driven distance. In the example of the case study from the deep drilling industry, maintenance levels are performed according to operating time of the system. Within this category lifetimes of the parts are compared regarding their fitting to the maintenance strategy. If one or a few parts trigger a specific maintenance, it can be cost-efficient to increase the lifetime of these parts to extend the maintenance of the whole system.

The next category analyzes the consumable parts of the systems. Consumables are defined as parts that are scrapped without inspection within a maintenance. These are often rather low-cost parts like O-rings or screws. However, with high quantities and frequent maintenance intervals they offer also offer significant cost optimization potentials. Consequently, the review includes analysis of using low-cost parts (because they are scrapped after a specific amount of time anyway) or long-life parts as well as changing the position to reduce wear on the part.

The two last review categories entail modularity and standardization. Modularity is an important aspect within maintainability. Reducing the variety of parts offers the opportunity to simplify maintenance activities. This aspect is analyzed in the review. The review indicates if similar parts or assemblies already exist in the internal design database. Last, the rate of standardization of standard components is determined. For example, all screws within the bill of material are analyzed on their characterizing parameters (e.g., thread, length, material). On this basis very similar parts are identified and proposed for a potential standardization. During the CapEx optimization, the developer is supported in all these categories by the computer-aided tool with fully automated analysis. As well, a morphological box for the OpEx optimization is generated (see Figure 7).



	alternative 1	alternative 2	alternative 3
(dis-)assembly position	keep the design	isolate part	change position
(dis-)assembly shape	keep the design	change design	combine parts
lifetime	keep the lifetimes	change design for adjusted lifetime	change design for cheaper repair
consumable	no change	change to lower cost part	change position for lower wear
modularity	no change	change part to modular approach	change for modularity throughout assembly
standardization	no change	lower number of different types	change to standardized part

Figure 7. Example of filled morphological box - OpEx

4.3 Relations and Trade-offs between CapEx and OpEx

As mentioned in section 2, a separate optimization of CapEx and OpEx is not productive. Trade-off between individual cost categories must be identified. The relations between all described categories are depicted in Figure 8.

Capital Expenditures \ Operational Expenditures	(dis-)assembly shape	(dis-)assembly position	maintenance strategy	consumable parts	modularity	standardization
standard / COTS product	×	×	●	●	●	●
material	×	×	×		×	
surface quality	×				×	
tolerances	×					
manufacturing process					●	
radii	×				×	×

● general relation
× possible opposed relation

Figure 8. Relations and Trade-Offs in CapEx and OpEx optimization

When optimizing an element according to a specific cost category, the developer gets informed on which possible trade-off can occur. This enables a holistic optimization of the life cycle costs.

5 CASE STUDY

The described optimization tool is developed with the industry. Companies with hybrid business models are focussing, beside manufacturing cost, on their operational efficiency. Often products are not sold but used to offer services. Therefore, it is essential for these companies to take CapEx as well as OpEx into account.

The developed cost driver optimization approach was applied in several current development projects in a global leading oilfield services corporation. The key objectives during development of this model were to improve the operational efficiency with longer intervals between maintenance cycles and increased reliability in these longer intervals, both tasks aiming at reducing non-productive time for the service provider's customers and increasing the competiveness of the offered services.

Figure 9 shows an exemplary drilling tool with identified and implemented design changes due to the cost driver optimization tool. All cost drivers became iteratively estimated and then analyzed with the described optimization approach.

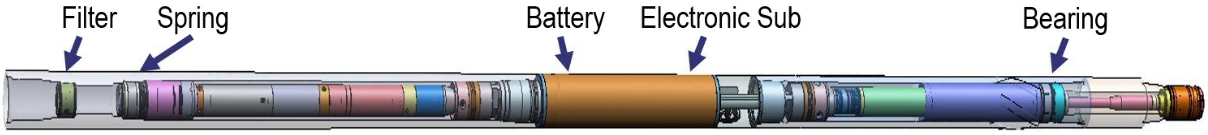


Figure 9. Case study with demonstrator drilling tool

As depicted, changes were distributed over the drilling tool and could not be assigned to a local design problem. The design of the filter was adapted regarding flow optimization. With casting instead of milling and welding, a new manufacturing process was chosen, reducing the CapEx. Due to reduced wear, according to the new design, OpEx of the part could be decreased as well. The wave spring was replaced by an existing and less-expensive version. This replacement significantly reduced OpEx, because of the spring's frequent scrap rate. The battery had a limited lifetime that could expire, independently of current job situation. Time-intensive maintenance of this component was required. To avoid unnecessary maintenance, the position of the battery was changed. This change slightly increased CapEx, but offered a more efficient maintenance. Overall, this trade-off decision enabled a large reduction of labor costs as well as an increased availability of the system.

The electronic sub is another main component of the drilling tool and a cost driver as well. The sub material was changed, resulting in an increase of the component length due to stress requirements. This trade-off was reviewed and the most cost-efficient solution was chosen. Bearings were also identified as a cost driver. Bearings in drilling tools often contain industry diamonds, making them expensive in CapEx and OpEx. Analysis revealed that the design could be adapted to reduce the number of diamonds without limiting performance.

For the whole drilling tool, analysis was performed on possible standardization of screws as well as seals. Analysis showed that comparatively inexpensive parts impact operative cost, due to their high quantity in the product and their frequent rate of scrap during maintenance.

Numerous other identified savings potentials identified with the optimization tool are still under investigation or implemented in other development projects.

After every optimization, the product life cycle cost was calculated with the cost estimation models (see Figure 5). This approach revealed that, on average, 3 to 10% of the life cycle cost could be saved, allowing cost savings to be passed on to the customers. In addition, due to the improved operational efficiency with longer times between maintenance, the reliability of the product was significantly increased. The case study revealed that is was very important to implement the process and apply the model within the design phase, eliminating cost for changes. The approach also displayed its high cost-value ratio.

6 CONCLUSION AND OUTLOOK

Beside technical aspects, the cost effectiveness determines if a product is successful on the market. For maximizing profit, life cycle costs are an important factor. This paper presents a holistic life cycle costing approach. The focus is on a systematic approach to optimize cost drivers based on the results from iterative life cycle cost estimations that use different prediction models. To optimize life cycle cost, CapEx as well as OpEx are considered. Both optimizations include six categories with three review levels each. This approach enables a fast, efficient and standardized process to determine cost-saving potentials. Possible trade-offs between the cost categories from CapEx and OpEx are also analyzed. The model is implemented as a computer-aided software tool to support the developer in a maximum way.

The developed approach guarantees a standardized procedure that offers reproducible and documented results. Subject matter experts can be specifically selected and interviewed when needed in the design process. Finally, a case study presents an exemplary application of the optimization tool in a global leading oilfield services company. Future work could be done to consider more product life cycle phases and the development of computer-aided support within the trade-off decisions.

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